SPECTRUM OF THE RADIATION FROM A HIGH POTENTIAL X-RAY TUBE

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Abstract

A spectrograph of the Seemann type has been constructed for the purpose of investigating the radiation from the high potential x-ray tube at the California Institute. A typical spectrogram obtained with 600 kilovolts on the tube is presented. The photometer record shows a continuous spectrum with its maximum intensity at about 200 kilovolts and a short wave-length limit in the neighborhood of 600 kilovolts. The range covered is roughly from 100 to 20 x-units. It is proposed to use the apparatus for determining absorption coefficients by photographing the spectrum of radiation which has passed through an absorbing screen. No anomalies of any kind have been observed so far.

Apparatus

The high potential x-ray tube at the California Institute of Technology has recently been rebuilt and equipped with a hot cathode and a tungsten target. A description of the tube and its housing has been presented by Lauritsen and Cassen.[1] The tube in its present form operates satisfactorily at 600 kilovolts and it has been deemed advisable to investigate the available radiation before attempting to go to higher potentials.

In order to investigate the region of the x-ray spectrum from approximately 150 kilovolts and up, a crystal spectrograph was constructed following the principle described by Seemann,[2] Siegbahn[3] and others. High precision cannot be expected with any reasonable time of exposure by this method since the whole of this region of the spectrum lies within an angle of less than one degree and thick slits are required because of the great penetrating power of the hard radiation. On the other hand, the method is convenient and sufficiently precise for the approximate determination of the short wave-length limit as well as of the general distribution of intensity in the spectrum. Also, if any prominent lines, bands or absorption edges or other unexpected irregularities exist in this region, they should be found most conveniently by this method.

The spectrograph consists essentially of a vertical slit 0.9 mm wide in a lead block 4 cm thick, in front of which a rock-salt crystal is placed. The crystal, slit and photographic plate are all rigidly mounted on a long arm which may be rotated through an angle of one degree on each side of the center, the rotation taking place about an axis through the vertical center line of the slit. Since the focal spot has the appearance of a thin horizontal

[1] C. C. Lauritsen and B. Cassen, Phys. Rev. **36**, 988 (1930).
[2] Seemann, Phys. Zeits. **18**, 242 (1917).
[3] M. Siegbahn, Phil. Mag. **2**, 639 (1919).

disk approximately 5 mm in diameter, it is clear that radiation will reach the central planes of the crystal under all angles from zero to 50 minutes, provided that the distance from the focal spot to the crystal does not exceed 35 cm and that the spectrograph arm is set at an angle of 25 minutes on either side of the center line through the focal spot and the slit. Under these conditions the undeviated part of the light will produce an image of the focal spot as seen through the slit, the whole of the image being located on one side of and adjacent to the center line of the photographic plate. The reflected portion of the light will appear as a spectrum on the other side of the center line. The short wave-length limit is thus given by the distance from the center line to the edge of the continuous spectrum, and lines of equal wave-length are parallel to the center line. Since different wave-lengths originate from different lateral regions of the focal spot and since the intensity is not absolutely uniform throughout the whole of the area, it is not possible to obtain the intensity distribution in the spectrum directly with any degree of precision. Correction can, however, be made for this lack of uniformity

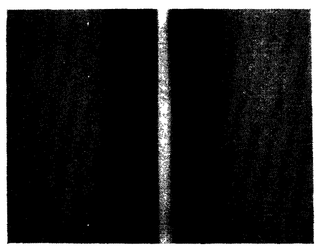

Fig. 1. Double spectrum 600 kv peak.

if the direct beam is reduced by means of a filter to an intensity comparable to the intensity of the spectrum. This is so because the direct beam is a true image of the focal spot and the spectrum is a specular image of the direct beam, except for the wave-length selectivity, and there appears to be no good reason why the radiation from different parts of the target should differ appreciably in hardness if the intensity is the same.

The photographic plate is placed 107.5 cm from the center of the slit. In spite of this comparatively great length, the resolution is not high on account of the wide slit, but it is sufficient for the present purpose.

In order to determine the exact zero on the photographic plate it is most convenient to photograph both right and left hand spectrum on the same plate. This is done by adjusting the spectrograph as described except that the direct image is blocked out completely by a heavy lead screen while one spectrum is being photographed. The spectrograph arm is then rotated into position on the opposite side of the center line and the direct image which now appears on the part of the plate which has been exposed is blocked off. The second exposure thus gives a spectrum on the part of the plate which was covered up during the first exposure. The result is two spectra which are symmetrical with respect to the center line or true zero. Fig. 1 is a positive reproduction of a double spectrum taken in this manner.

A dark line may be seen running diagonally through the spectrum in each of the spectra of Fig. 1. The origin of this line becomes apparent if we consider the geometry of the arrangement. The spectrum shown is due to reflection from vertical (100) planes of the rock-salt crystal, but if the crystal is adjusted so that the horizontal (100) planes are parallel to a horizontal plane through the focal spot and some part of the photographic plate, then it is clear that from each point of the target there will be a ray of a given wave-length which will make the same angle with the horizontal as with the vertical planes. The intensity of this ray will therefore be divided between the spectrum shown and a spectrum which falls above, below, or within the direct image.

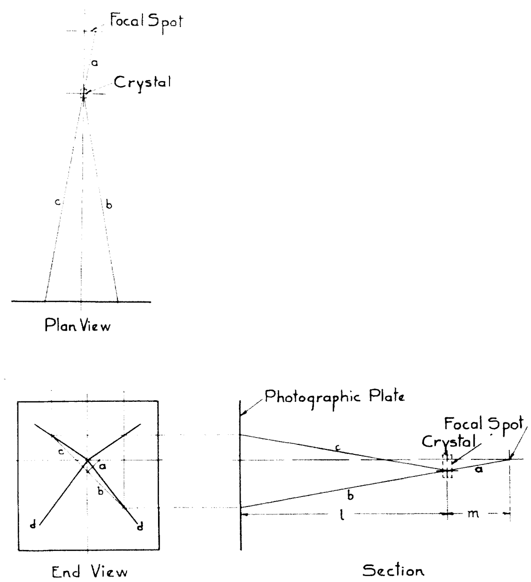

Fig. 2.

This second spectrum is of the type first obtained by Rutherford and Andrade and differs from the first in that the resolution is slightly less. The paths of a ray are shown by the lines a, b and c in Fig. 2, and the heavy lines d in the end view are the intersections with the photographic plate of all the rays which fulfill the foregoing condition. It is readily seen from the figure that the angle between the lines d and the vertical center line is given by

$$\tan\theta = \frac{b}{a+b}\cdot$$

In the present case, this gives

$$\tan\theta = \frac{107.5}{142.5} = 0.755;\ \theta = 37.05°$$

which agrees with the angles made by the dark lines in Fig. 1 with the center line.

The intensity distribution was obtained by means of a recording microphotometer. In Fig. 3 the galvanometer deflections obtained from the photometer records are plotted as ordinates against distance as abscissas. The tube was operated at 600 kilovolts peak and, as indicated in the graph, the short wave-length limit corresponds closely to this value. The maximum intensity occurs somewhat below one half of this potential, as might be expected since the tube is operated with alternating current and a "thick"

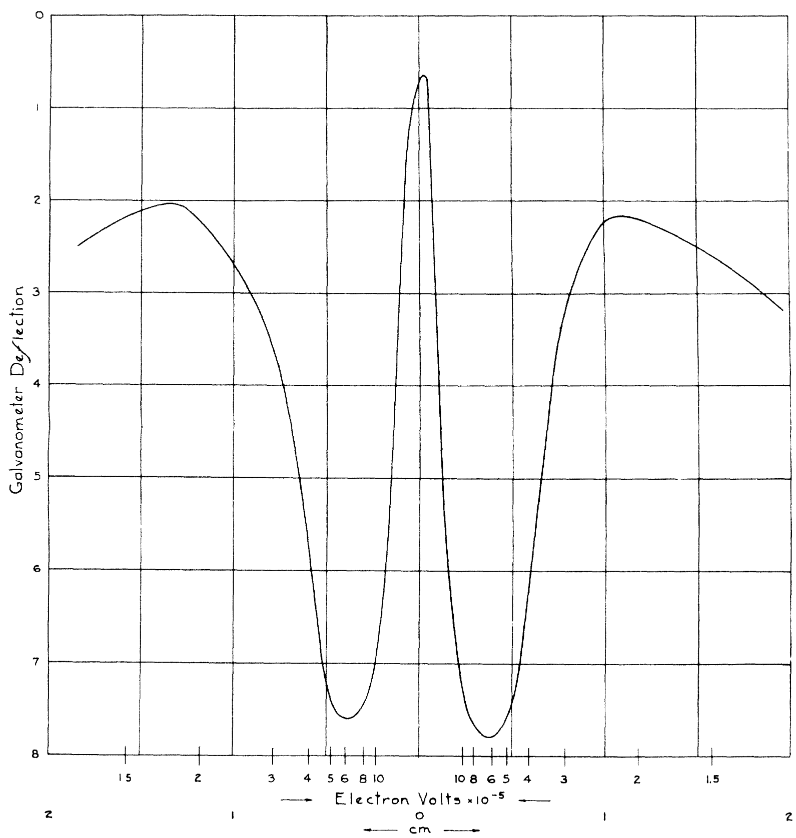

Fig. 3.

target is used. It should be noted, however, that the softer radiation is decreased somewhat in passing through both the 6 mm steel wall of the tube and the crystal. The lack of symmetry which is apparent in the graph is due partly to the aforementioned non-uniformity of the focal spot and partly to a slight difference in exposure.

Results

From the photograph as well as from the photometer record we may conclude that, within the limits of the resolution used, there are no unexpected irregularities in the spectrum from tungsten in the region covered.

At the present time work is in progress to determine as accurately as possible how the spectrum is modified by different absorbers. The right half of Fig. 4 shows the spectrum after passing through lead screens. One screen, 0.28 in. thick, covers the whole image, and in addition the central portion is covered by a second screen 0.14 in. thick. The direct beam was decreased to a suitable intensity by a steel block 2 in. thick.

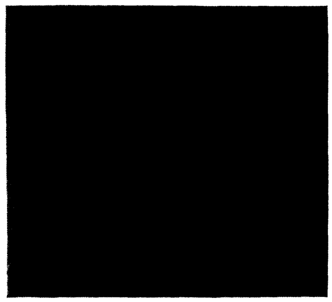

Fig. 4. Left, direct image. Right, spectrum.

The photometer records of spectra taken in this way show accurately how the spectrum is modified by any given absorber and it should therefore be possible to obtain from a single pair of records the absorption coefficient as a function of the wave-length.

If nuclear absorption levels or other unexpected irregularities exist in this region of the spectrum, they should be readily detected by this method. The spectra obtained so far and also the modifications due to absorbing screens of aluminum, iron, copper and lead are roughly what would be expected. There is no indication of any sudden changes in intensity with wave-length.

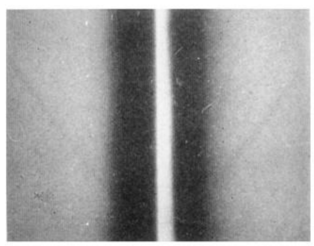

Fig. 1. Double spectrum 600 kv peak.

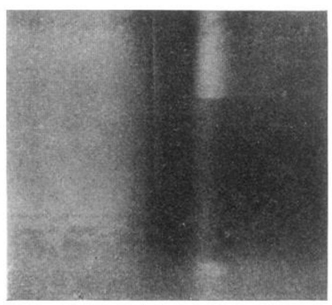

Fig. 4. Left, direct image. Right, spectrum.